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Ecological Restoration and Water Flow Improvement For Food Security in the Context of Changing Climate: Learning from Small-holder Farmers of Southern Tanzania

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Abstract

Wetland ecosystems are estimated to cover 10% of the land surface area in Tanzania. Human activities, together with environmental factors such as climate change, have been pointed out as a major threat to the services they provide on climate and flood regulation, water and food provisioning, sediment removal, and human welfare, among others. Various efforts have been undertaken to restore the ecological functions of wetlands in different areas of Tanzania. However, insufficient attention has been paid to understanding the impacts of restoration efforts on the sustainability of water access for people who have been influencing such efforts. This study investigated whether the ecological restoration efforts introduced in the wetlands of southern Tanzania between 2005 and 2011 had improved the flow of water for wetland agriculture to the people of the area in the context of a changing climate. The TREND v. 1.02-time series software was used to determine water flow in the sampled restored wetland. To supplement quantitative data, interviews and direct observation methods were used to get social and qualitative information from the people in the area on the trend for water flow. The results showed three key findings: (i) wetlands restoration efforts have not achieved remarkable results since the flow of water has declined from 6.3 m3/s before, to 4.7 m3/s after restoration efforts; (ii) the flow of water in wetlands ($r = 0.37$) is more explained by factors other than rainfall ($r = 0.27$), and that human activities have contributed to the decline in flow; and (iii) there is a close relationship between culture and wetlands, where sacred wetlands were found to continue releasing water all year round for food production, indicating that culture is one of the tools for water resources management in climate-risk environments. Therefore, studies on the importance of using sacred wetlands to conserve water for increased food production in a space-limited wetland system with zero water loss are recommended.

Keywords: *water flow, infrared, restoration, riparian; sacred*

Introduction

Wetlands are estimated to cover less than 7% of the global land area (Ngowi, 2018). Despite this small coverage, wetlands contribute significantly to the improvement of ecosystem services: climate and flood regulation, water and food provisioning, sediment removal, and cultural services (Ngowi & Mwakaje, 2020). Meanwhile, Ngowi (2018) reveals that the degradation of wetlands is increasing in many areas worldwide, and that the degradation intensifies human-environment conflicts, particularly in the world's poorest societies. Due to this, strategies have been

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introduced in many areas to address the problem. Some of the strategies include, but are not limited to, policy and regulations, payment for ecosystem services, offering financial incentive packages, and the establishment of protected areas (Ngowi and Mwakaje, 2020). According to these authors, evidence shows that some of these strategies have significantly contributed to restoring degraded wetlands.

Restoration ecology, as defined by Casagrande (1997), is the process of re-joining human and non-human characteristics of ecosystems, and humans are required for evaluating the success of the restoration efforts. While most restoration efforts have been reported in Europe and the USA, many efforts from other regions are scantly reported (Nakamura et al., 2006). However, restoration strategies such as reducing farming and grazing area, destocking, changing food and fuel consumption patterns, and seeking off-farm incomes, among others, seem to affect the sustainability of food, fuel, fresh water, clean air, and recreation services (Zhen et al., 2022). As a consequence, affected societies are obliged to change their behaviour to cope with these changes. This is because the changes result in the transformation of lifestyles. The main and more intriguing question, therefore, is how to protect natural ecosystems while promoting socio-economic development. That means conflicts arise between ecological systems and social systems through land use and land cover changes. In social systems, population, economic structure, institutions, culture, and technology affect land uses. In this process, key components of ecosystems subsequently change biochemistry, biodiversity, water, air, and soil. As a result, land transitions and interactions between land use and land cover affect ecosystem functions. Zhen et al. (2022) show that soil erosion control strategies through tree planting in China have consumed huge amounts of water, thus reducing water supply through transpiration, infiltration, and interception. On the other hand, ecological restoration has increased soil organic carbon and vegetation carbon sequestration, thus enhancing water purification.

A study by Casagrande (1997) in Connecticut, US, shows that ecological restoration of degraded environments such as wetlands has enhanced social structures as well as non-human ecosystem structures such as climate, relief, and water. Farmers not only benefit economically but also facilitate the ecological processes responsible for biomass productivity. Carke et al. (2021) show that the interaction of people with their environment and activities that relate people to one another and their environment have impacted the human characteristics of ecosystems in South Australia. Nausser (2004), on the other hand, shows that cultural sustainability is a long-term success for the restoration of wetlands in Minesota, USA. Bishop et al. (1998) show that restorations have increased wetland areas for the protection of the riparian corridors along people's recreational opportunities and the state of Iowa economically.

On food security, Munang et al. (2011) show that ecosystem-based management initiatives are the basis for increasing local people's food security, livelihoods, and long-term economic and environmental sustainability, and so achieving the United Nations (UN) sustainable development goals (SDGs). For instance, Wantzel et al. (2019) show that in the Ekozoa stream of Yaoundé, Cameroon, the riverine wetlands are used for subsistence horticulture by local residents nearby. While farming is not allowed, this form of subsistence farming is important to combat social unrest. McKersie (2015) shows that people have different options to ensure food security caused by climate and/or societal changes. However, not all options are effective in the short-term, and some may not be practical due to increased demands on limited resources, including water.

In Tanzania, wetlands are estimated to cover about 10% of the land area, and they play a greater role in soil formation, nutrient cycling, regulating climate and flooding, providing water and food, providing aesthetic and spiritual services, grazing land, etc. (Figure 1). Concerns about the degradation of wetlands and the loss of services they provide are a significant national issue (URT, 2006). To address this problem, the government of Tanzania began promoting ecological restoration in rivers, lakes, grassland wetlands, and catchments in the 2000s. The early strategies were dominated by the identification and protection from socio-economic development of areas with potential for biodiversity conservation by establishing wetlands of international importance, or Ramsar sites. The Ruaha Water Programme, under the WWF Tanzania Office that ran from 2003 to 2008, was one of the programs that aimed at restoring all-year-round flows of water in the Great Ruaha River, as well as enhancing wetland conservation, livelihood improvement, and other natural resource management. These strategies aimed at improving the long-term water flow in the wetlands.

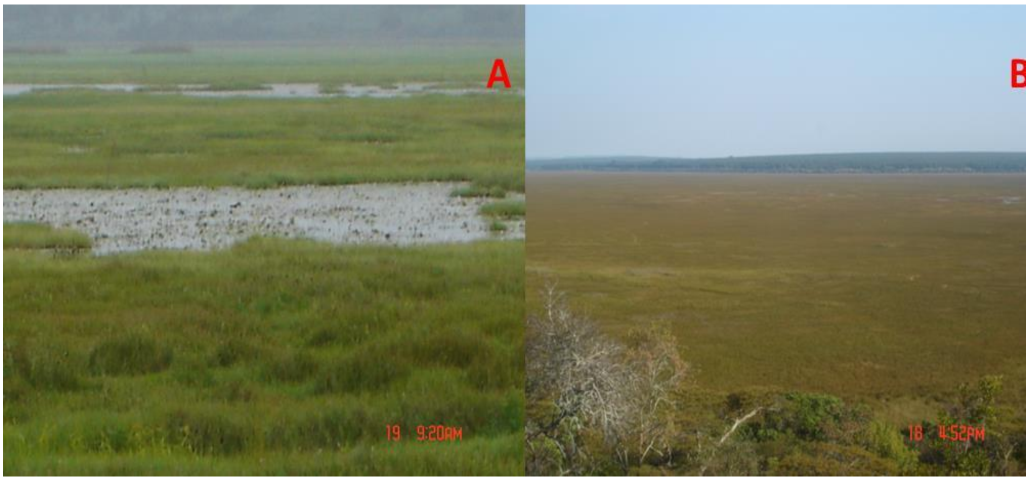

Figure 1: Wetlands in Various Seasons: (A) Water in the Rainy Season and (B) Grazing Habitat in the Dry Season

Source: Field Survey (2021).

To ensure that this is effectively conducted, a 10-year sustainable wetlands management program—funded by the Denmark's Danish International Development Authority (DANIDA) and the Belgian Technical Cooperation (BTC)—was introduced in different regions with—and without—Ramsar sites to restore degraded wetland sites across the country by the Ministry of Natural Resources and Tourism, and the Ministry of Foreign Affairs of Denmark (2003). Parallel to this approach, incentives in the form of tree planting, wetland reclamation from cultivated wetlands, river banks, decreasing numbers of livestock, the establishment of aquaculture, and bee forage were introduced to encourage the relocation of local communities from degraded wetlands to other areas to allow degraded wetland sites to recover (Ngowi, 2018). These restoration efforts that Tanzania has undertaken in restoring degraded wetland ecosystems have been dominated by human-centred approaches, with a relatively small contribution from natural solutions such as ecosystem protection to allow natural recovery.

Despite some notable achievements in ecological restoration and associated impacts on environmental systems around the world, and Tanzania in particular, little is known regarding the evaluation of the impacts of restoration efforts on the water security of the people who have been affected, on the one hand, and the people who have influenced the implementation of the restoration efforts, on the other (Ngowi & Mwakaje, 2020). This has raised concerns over the sustainability of ecological restoration efforts. Therefore, the objective of this study was to explore the effect of ecological restoration activities on the flow of water, especially for the people who are living in and around some selected wetlands of local importance in the southern highlands of Tanzania.

Hence, drawing on data from the southern highlands of Tanzania, this paper presents strategies for securing sustainable water for poor local communities for agriculture and for fighting climate change, which are among the major global development agendas within the discipline of environment as a cross-cutting issue. These issues are also in line with the United Nations' SDGs: Goal 1: poverty; Goal 2: hunger, food security, nutrition, and sustainable agriculture; Goal 12: forest, land degradation, and biodiversity loss; Goal 13: climate action; Goal 15: improving life on land; and Goal 17: partnerships. Similarly, these issues are also within the focus of two of the three objectives of the Tanzania Development Vision 2025: (i) achieving quality and a good life for all; and (ii) building a strong and resilient economy that can effectively withstand global competition.

Methodology

Description of the Study Area

The study was conducted in the Iringa and Mufindi districts of the southern highlands of Tanzania. The selection criteria were based on the justification that these were the first sites among new sites to pilot ecological restoration of wetlands. It was expected that the findings from these sites would offer the best lessons to inform policy compared to other wetlands areas in the country. The study was carried out during the dry and wet seasons to capture all seasonal dynamics.

The climate of the wetlands of the study area falls into two major climatic zones: the *eastern zone,* with an altitude ranging from 1600m to 2200m above sea level, and an annual rainfall of 1000mm to 1200mm; and *the western zone,* with an altitude of 1000m to 1200m above sea level, and an annual rainfall ranging from 600mm to 750mm. The soil is typical *black cotton,* which forms large cracks when dry after being flooded in the rainy season. The seasonally flooded area is dominated by *Acacia seyal, Acacia tortilis,* and *Acacia kirkii*. The dominant plant communities are swamp forests, seasonally flooded grasslands, and dominant *Acacia* woodlands. Herbaceous swamps interspersed with seasonally flooded grasslands and forests support the biodiversity of many waterbirds. Ngowi (2018) reports that, depending on local conditions, grassland wetlands provide grazing areas for livestock and wild animals during the dry season.

Pawlak and Kolodziejzak (2020) identify the major socio-economic activity in the study area as agriculture, as it applies to most low-income countries, which, among others, aims at achieving food as well as nutrition security. The study area forms part of the Ihemi Cluster of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) (Minde, 2017). The SAGCOT is a public-private partnership initiative designed to enforce the *Agriculture First Policy,* with the aim of increasing income and employment opportunities using the agribusiness value chain in the southern corridor of Tanzania (https://www.iisd.org/savi/project/southern-agricultural-growth-corridor-of-tanzania/). The landscape of the study area is dominated by inland wetlands with fertile soils, a high water table, and nutrients allowing moisture release during the dry season, thus supporting the production of maize, beans, rice, and horticultural crop production during the dry season of the year (Kyando, 2007). Of significance is wetland agriculture (locally known as *vinyungu* (valley-bottom agriculture)), which is one of the traditional agricultural systems carried by smallholder farmers in the southern highlands of Tanzania (Majule, 2010; Majule & Mwalyosi, 2005). This agricultural system utilizes naturally available moisture and water in the wetlands to produce food and income for smallholder farmers (Kyando, 2007).

Over the years, valley-bottom agriculture has been intensively utilized during the dry seasons because the landscape of the southern highlands of Tanzania—and the Ihemi Cluster of Iringa district (Iringa District Council, 2013) in particular, which is the focus of this study—is dominated by high water tables; and therefore is ideal for increasing food production and supporting the livelihoods of small farmers in a changing climate (Kyando, 2007; Majule & Mwalysosi, 2005). Both valley-bottom agriculture on the low landscapes and farming on the higher landscapes are essential for ensuring food and income security of smallholder farmers, as well as contributing significantly to the downstream siltation. The implications of changing the water flow and agricultural systems during a changing climate are not well known. Hence, this work was planned to fill this knowledge gap using Iringa District as a case study.

Research Design, Sampling Procedure and Sample Size
This study used an explanatory sequential design approach for quantitative and qualitative data collection and analysis, as explained in Creswell and Clark (2007) (Figure 2). A combination of both approaches was ideal for a better understanding of the problem being investigated.

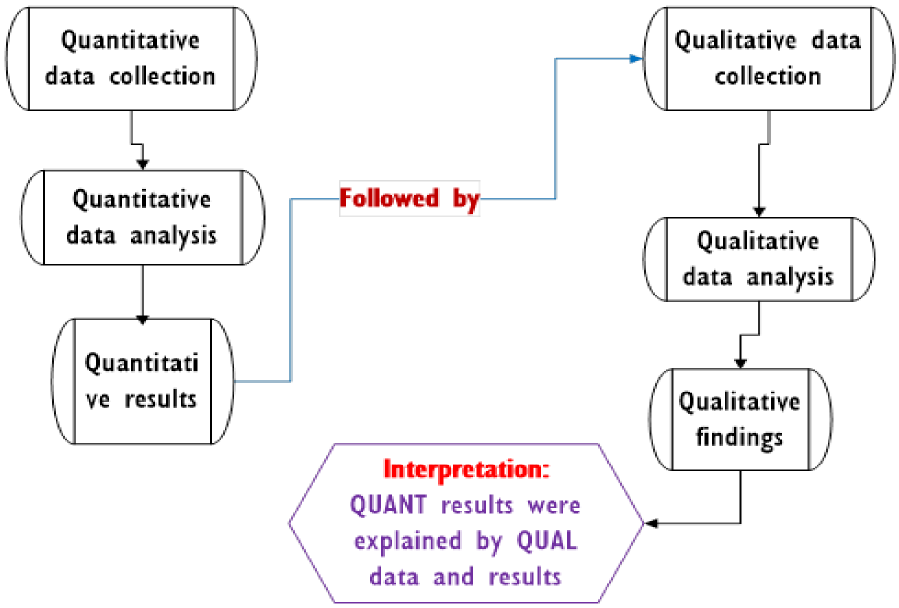

Figure 2: Explanatory Sequential Design Steps Adopted for Data Collection and Analysis (Ngowi and Ngalawa, 2023)

Data Collection, Processing and Analysis
This study used both secondary and primary data sources. The secondary data were collected through a documentary review of various published reports and web pages, followed by the primary data.

Quantitative Data
Determination of Rainfall and Water Flow in the Wetlands
The TREND (ver1.02) software (Chiew & Siriwardena, 2005) and MS Excel were used to study the 30-year monitored water flow and rainfall data from 1985/86 to 2015/16 in the sampled wetlands using historical rainfall and water flow data from public institutions (Rufiji Basin Water Office, and Tanzania Meteorological Agency). This was supplemented by Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) (Funk et al., 2015) to come up with the trend (Table 1). The TREND software was preferred because it is an open source, and also produces results at 99%, 95%, and 90% test statistic levels of significance.

Table 1: Long-Term Rainfall and Water Flow Trend: 1985/86–2015/16

Year	Rainfall (mm)	Flow (m^3/s)
1985/86	45.32043056	7.92
1986/87	76.43061411	11.43
1937/83	67.46346585	6.36
1938/89	72.12734371	4.133
1989/90	94.40450482	8.855
1990/91	74.31097029	4.889
1991/92	76.10212409	3.932
1992/93	70.31762619	6.746
1993/94	67.4855661	4.980
1994/95	80.52945237	4.113
1995196	77.62119208	4.856
1996/97	69.8355901	3.569
1997/98	83.51333478	22.294
1999/00	78.14588639	3.059
2000/01	67.21854444	7.273
2001/02	66.9498406	5–720
2002/03	67.68248223	2.468
2003/04	69.31865947	3.351
2004/05	55.11789783	4.311
2005/06	84.10820837	2.541
2006/07	50.14780339	6.475
2007/08	82.64319633	6.731
2008/09	69.18615794	5.742
2009/10	78.96846484	5–840
2010/11	86.75098809	2.482
2011/12	54.42893334	3.200
2012/13	82.31603108	4.415
2013/14	64.60731207	8.000
2014/15	63.49923702	5.000
2015/16	88.00998174	6.430

Source: Field Survey (2014)

The TREND software was used to study and compare the rainfall and water flow patterns in the sampled wetlands after the introduction of restoration activities with a baseline (before restoration). The difference in means before and after the introduction of the restoration programmes was analysed using a t-test to check their significance at the baseline, as explained by Evans (1996).

Social/Qualitative Data

A checklist of interview questions with 15 key informants and 30 participants of the focus groups, each having 6–8 members, was used to get social and qualitative information, including the attitude of the people in the area toward the trend of water flow, to supplement themes not captured in the quantitative data. The direct observation method was used to obtain data on the socio-ecological status of the restored wetlands. A description method was used to present qualitative data collected through focus group discussions (FGDs), and personal observations. To enhance clarity and better understand the subject, presentations have been supported by figures and direct statements from participants in the FGDs. The sequence presented in Figure 2 shows that the quantitative information collected first helped inform the qualitative step, and later assisted in the analysis and interpretation of the earlier data.

The interview was conducted from August 2015 to May 2016. The interview questions were constructed in Kiswahili because all respondents were fluent in both Kiswahili and the local languages (Hehe and Bena) spoken in the study areas. The meaning of wetlands was given in local terms to ensure that respondents understood exactly what was referred to as wetlands in this study.

Results and Discussion

Rainfall and Water Flow/Quantitative Results

The mean annual historical rainfall and water flow patterns in the sampled restoration areas revealed no variation in flows (Figure 3). A small deviation existed where the period with the highest rainfall did not have the highest flow, and vice versa. For instance, in 1989–90, the mean annual rainfall was 94.4mm with a flow of 8.86m^3/s, while in 1997–98, the mean rainfall was 83.5mm with a flow of 22.3m^3/s. The results show that the nature of the picks (the period with the highest mean flow of 22.294m^3/s recorded in 1997/98) is not necessarily the same as the one with the highest rainfall of 94.4mm observed in 1989/90, and vice versa.

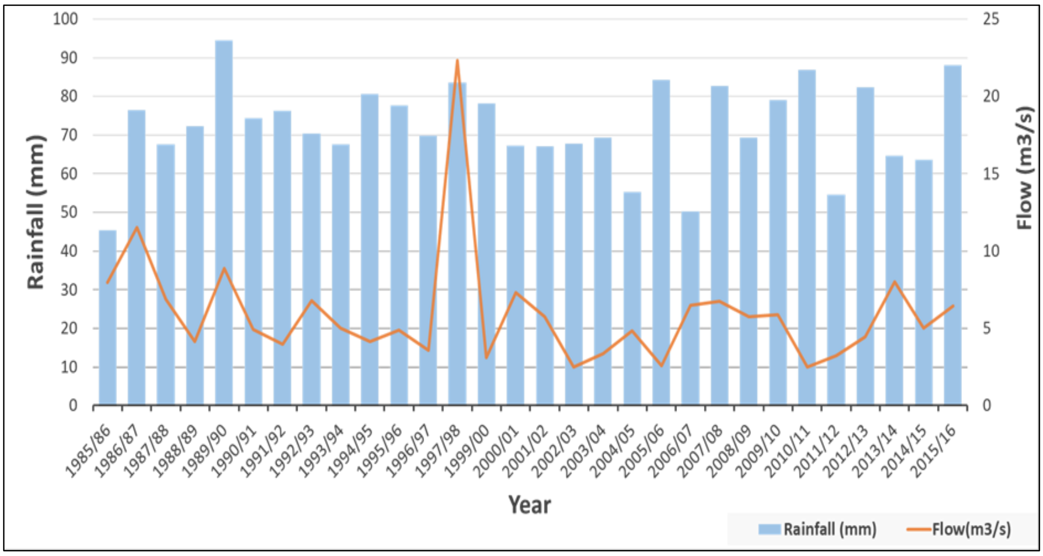

Figure 3: Thirty-Year Mean Annual Rainfall And Water Flow In The Sampled Wetlands.

Source: Survey data, 2016

A study on the correlation between water flow and rainfall parameters by Ngowi (2018) shows that a variation in flow is very little explained by rainfall (27%, $r = 0.27$) (Figure 4A) compared to outlier factors (37%, $r = 0.37$) (Figure 4B). The correlation revealed that rainfall had not significantly affected water flow. It implies that, despite receiving high annual mean rainfall (above 80mm) in some areas, the flow of water in the sampled restored wetlands dropped after the introduction of the ecological restoration activities.

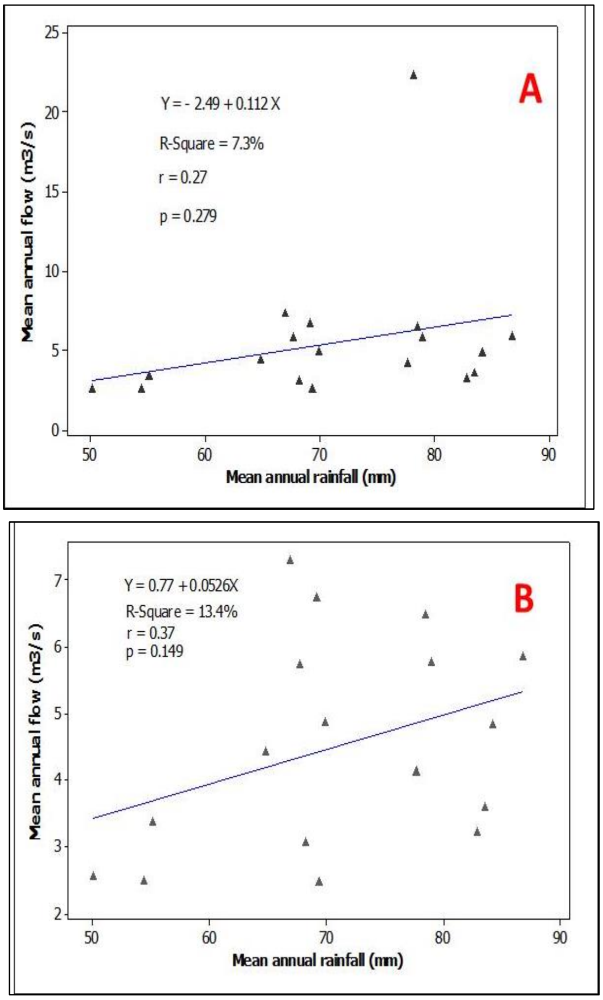

Figure 4: Correlation of Water Flow With Outliers (A) and (B) Without Outliers (Ngowi & Mwakaje, 2020)

The results from the comparison of the nine-year water flow before and after ecological restorations in the sampled wetlands, where restoration programs were introduced, indicate that there was no difference in flow during these two periods (Figure 5A). The flow of water per meter cubic per second (m^3/s) before restoration was highest at 22.3m^3/s, and lowest at 3.059m^3/s. After restoration, the highest and lowest were 8.469 and 3m^3/s, and 2.482 and22.3 m^3/s, respectively. The paired t-test results show that a mean water flow (before) of 6.3m^3/s does not differ much (after restorations) from that of 4.7m^3/s. However, the difference between the two periods was not statistically significant ($p = 0.9$, $p = 0.05$). The results show similar flow patterns were observed in the sampled wetlands selected in Ifunda, Lumuli, and Maboga wards, where rainfall variability had slightly impacted water flow (Figure 5B).

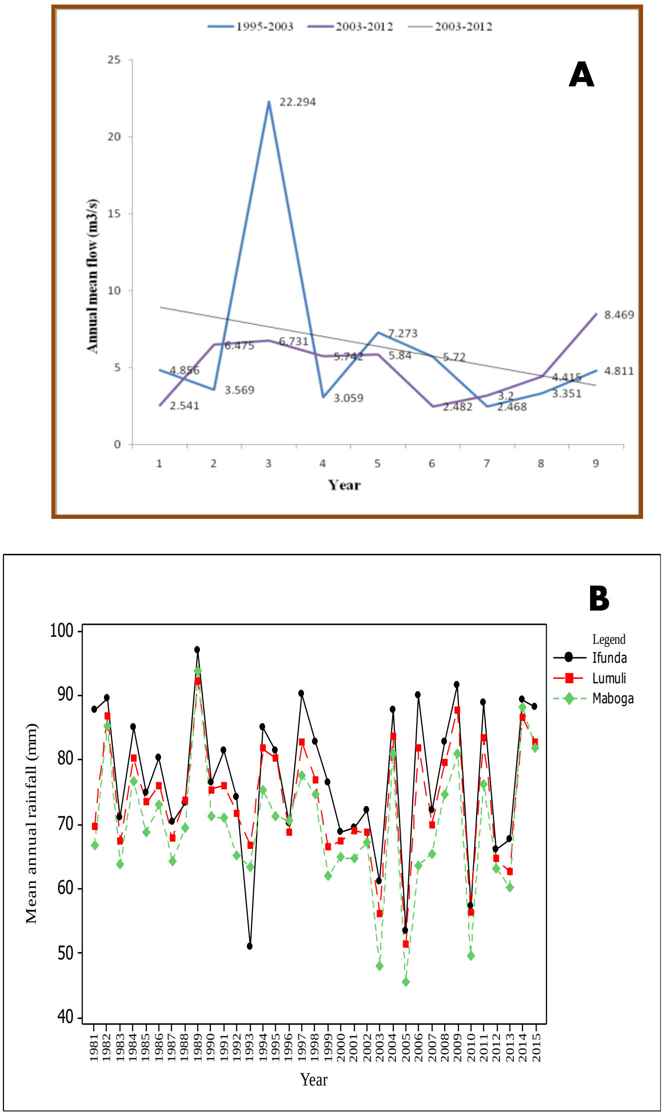

Figure 5: Water Flow in the Restored Wetlands (Ngowi & Mwakaje, 2020)

Social/Qualitative Results
The quantitative results in the previous section(s) are supported by qualitative findings from both focus groups with key informants in the sampled areas. The results showed that rainfall variability had a small impact on changes in water flow and that the latter was decreasing over a nine-year period despite restoration interventions. Human actions in the sampled areas were found to have prevented the flow of water in the restored wetlands. Forest clearance for agriculture on the higher landscapes has led to soil erosion and silt transportation on the river wetlands (see Figure 6A). This variable, combined with the wetland farming method of raising camber beds in the wetlands, prevented the flow of water held between one camber bed and another in the restored wetlands throughout the dry season (Figure 6B). According to Ngowi (2018), the wetlands of the study area are estimated to provide over 65,000ha of arable irrigated land for agriculture to smallholder farmers, whose 90% of their livelihoods depend on water flow in the wetlands for wetland farming or bottom valley cultivation, locally known as '*vinyungu,* during the dry season (RBWB, 2015). This type of farming comprises crops like tomatoes, onions, paprika, beans, and vegetables. Wetland farming has increased competition for water demand among smallholder farmers because it is one of the major means of survival, as well as of reducing farmers' dependence on rain-fed agriculture. A study by Wantzel et al. (2019) in the Ekozoa stream, Cameroon, shows wetland farming is imperative for subsistence horticulture and food security to the local people in the adjacent areas.

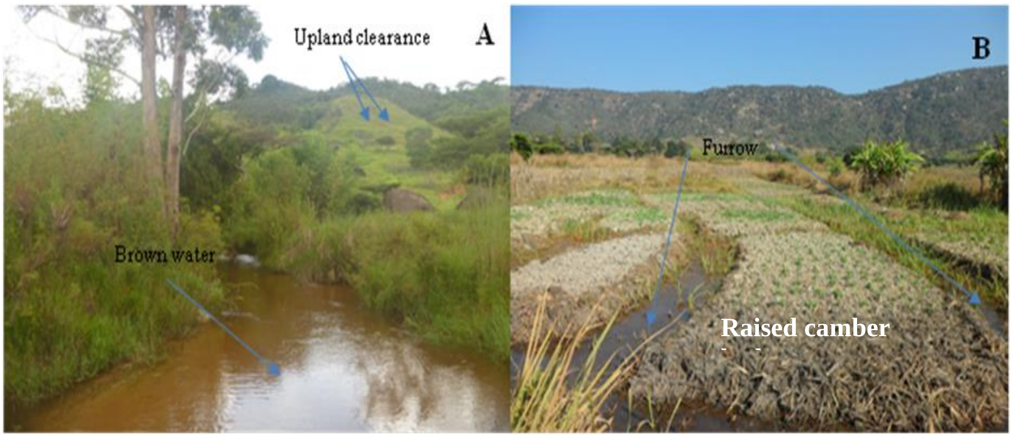

Figure 6. Drivers of Water Flow Prevention: (A) Forest Clearance and (B) Raised Camber Beds (Ngowi, 2018)

Studies by Magembe (2007) and Dixon and Carrie (2016) found that farming systems in *Dambo [1*] reduced water flows in Tanzania and Malawi. While a study by Gollin (2020) shows that traditional irrigation systems, commonly practiced by smallholder farmers in sub-Saharan Africa, seek to increase food production per unit of land area per agriculture worker, Majule and Mwalysosi (2005) report that siltation reduces the size of farms owned by smallholder farmers whose farms are smaller than 5ha of land, thus affecting food production in wetland farming in Tanzania.

The local community of the area, as it was also revealed in my personal observation, showed that wetlands protected by culture—in this case sacred wetlands, locally known as *litemera*—were least degraded compared to other wetlands where restoration activities were implemented. These findings were supported by an onsite direct observation method, which shows that sacred wetlands were found intact and realizing water services all the seasons for irrigated agriculture compared to other wetlands under the restoration programs in the sampled area (Figure 7).

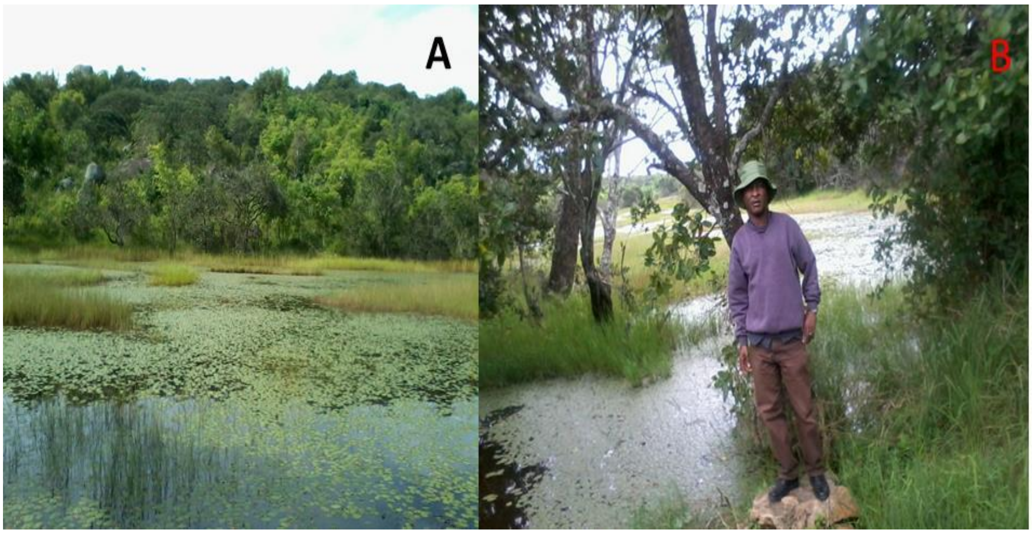

Figure 7: Sacred Wetlands, or *Litemera,* Release Water Throughout the Year
(Ngowi, 2018)

McKersie (2015), for instance, demonstrates that people have a variety of alternatives for ensuring food security in the face of societal and/or climate change, some of which are beneficial in the short-term, but may not be feasible in the long-run due to altered demands on finite environmental resources. These results support the researches by Ostrom and Hess (2000) and Dodouras and Lyratzaki (2012), which demonstrate that culture is the most effective institution for controlling the environment and the usage of natural resources.

With respect to the results of the study, this could be due to certain characters that local communities in the area consider violating customs and beliefs a sacrilege. Therefore, everyone seemed to fear putting this to the test, leading to most of these sacred sites being well preserved.

These results have provided a theoretical basis for the implication of water flow on food security in the study area. Despite water flow declines in the restored wetlands caused by differences in land uses and a changing climate, food production may still increase the future of food security in the area by utilizing space-limited wetland systems with virtually zero water loss and seasonal fish culture (Lamtane, 2009), where water and migratory fish are trapped in the rainy season (Figure 8A) and raised in satellite ponds (Figure 8B). These can be harvested in the dry season.

In addition, grassland wetlands (Figure 8C) serve as an alternative source of income to farming through brickmaking. Papyrus wetlands, on the other hand, form ecological buffer zones, protecting shallow wetlands from sedimentation and open water from eutrophication (Figure 8 D). The results of this study show that various wetland processes and functions support the wellbeing of adjacent riparian communities by improving their economies and providing clean water services. This cycling of certain activities in the wetlands reduces the local community's vulnerability to food insecurity, increases nutrition, and increases the income security of smallholder farmers.

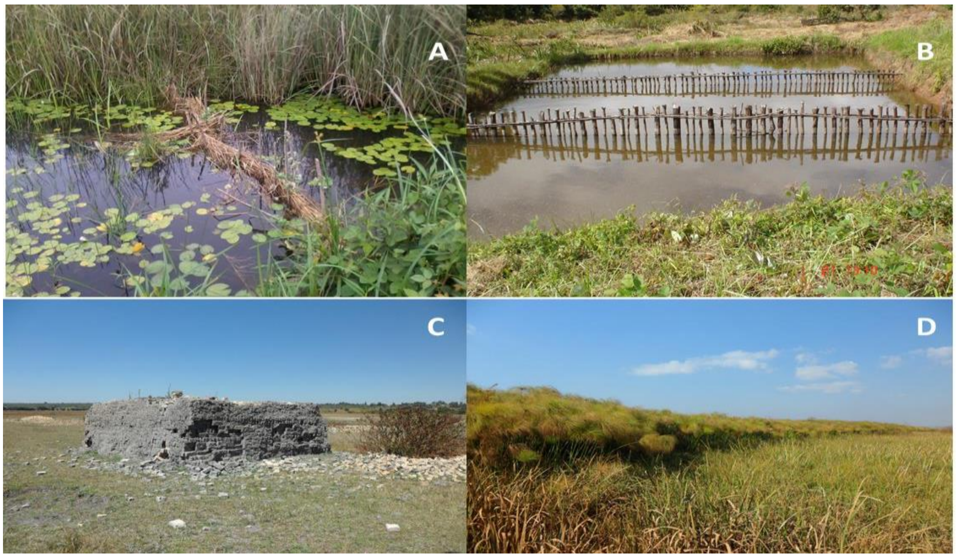

Figure 8: Cycling Use of Wetlands With Zero Water Loss: (A, B) Seasonal Fish Culture; (C) Bricking; (D) Papyrus Wetlands.
Source: Survey data, 2016

Conclusions and Recommendations

The study found that the flow of water in the restored wetlands has been declining despite the introduction of ecological restoration programs. Forest clearance for agriculture expansion has produced siltation, which—together with the raised camber bed method for wetland agriculture—has blocked water flow. Rainfall variability had a small contribution to the declines in water flow. This implies that the decline in water flow represents a failure of the ecological restoration programs, suggesting that ecological restorations alone are not sufficient for complete improvement of the desired water flow. The study discourages the expansion of agricultural land through forest clearance on the higher landscapes, and agricultural activities around the watersheds. This will enhance siltation and prevent water flow in the restored wetlands. A study on the options of using sacred wetlands to provide water for high-yield food production in space-limited wetland agriculture systems, as well as fishponds with zero water loss, is recommended.

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